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SHORTER ARTICLES AND DISCUSSION

STUDIES ON INBREEDING. VI. SOME FURTHER CONSIDERATIONS REGARDING COUSIN AND RELATED KINDS OF MATING¹

IN the first of these studies² the writer dealt with the results, in so far as concerned coefficients of inbreeding, which would follow continued brother $\times$ sister, parent $\times$ offspring, and cousin $\times$ cousin mating. Regarding matings of the latter type it is desired now to record certain further facts.

PEDIGREE TABLE I (HYPOTHETICAL)

TO ILLUSTRATE THE CONTINUED BREEDING OF FIRST-COUSIN $\times$ FIRST-COUSIN
— SINGLE COUSINS

Δ	{ a }	{ c e }	{ g h }	{ m n o p }	{ 1 2 3 4 1 2 5 6 1 2 3 4 1 2 9 10 1 2 3 4 1 2 5 6 1 2 3 4 1 2 7 8 }
Generation number	1	2	3	4	5

¹ Papers from the Biological Laboratory of the Maine Agricultural Experiment Station No. 85.

² AMER. NAT., Vol. XLVIII, 1913, pp. 577-614.

There are, of course, two possible sorts of first cousins, single and double. In the first case one of the parents of any individual is a brother (or sister) to the one of the parents of the other individual in the mating. In the second case, both the parents occupy this relation to the parents of the other individual in the mating.

These two sorts of first cousinship are shown in Pedigree Tables I and II.

PEDIGREE TABLE II (HYPOTHETICAL)

TO ILLUSTRATE THE CONTINUED BREEDING OF FIRST-COUSIN $\times$ FIRST-COUSIN
— DOUBLE COUSINS

Δ_2	$\left. \begin{array}{c} a \\ \\ \\ b \end{array} \right\}$	$\left. \begin{array}{c} c \\ \\ d \end{array} \right\}$	$\left. \begin{array}{c} g \\ \\ h \end{array} \right\}$	$\left\{ \begin{array}{c} k \\ l \end{array} \right.$	$\left\{ \begin{array}{c} o \\ p \\ q \\ r \end{array} \right.$
			$\left\{ \begin{array}{c} i \\ j \end{array} \right.$	$\left\{ \begin{array}{c} m \\ n \end{array} \right.$	$\left\{ \begin{array}{c} o \\ p \\ q \\ r \end{array} \right.$
			$\left\{ \begin{array}{c} g \\ h \end{array} \right.$	$\left\{ \begin{array}{c} k \\ l \end{array} \right.$	$\left\{ \begin{array}{c} o \\ p \\ q \\ r \end{array} \right.$
		$\left. \begin{array}{c} e \\ \\ f \end{array} \right\}$	$\left\{ \begin{array}{c} i \\ j \end{array} \right.$	$\left\{ \begin{array}{c} m \\ n \end{array} \right.$	$\left\{ \begin{array}{c} o \\ p \\ q \\ r \end{array} \right.$
Generation number	1	2	3	4	5

The values of the coefficients of inbreeding for continued single and double cousin mating are shown in Table I.

It will be seen that Pedigree Table I and the third column of Table I are different from the corresponding values given on pages 591 and 592 of the earlier paper. The present values should be substituted for the earlier ones, which were based upon

the erroneous assumption that half the double-cousin values would give single-cousin values.

TABLE I

VALUES OF THE SUCCESSIVE COEFFICIENTS OF INBREEDING IN THE CASE OF CONTINUED COUSIN MATING

Coefficient of Inbreeding	Ancestral Generation Included	Coefficient for Single Cousins	Coefficient for Double Cousins
Z_0	1	0	0
Z_1	2	0	0
Z_2	3	25.00	50.00
Z_3	4	50.00	75.00
Z_4	5	68.75	87.50
Z_5	6	81.25	93.75
Z_6	7	89.06	96.98
Z_7	8	93.75	98.44
Z_8	9	96.48	99.22
Z_9	10	98.05	99.61
Z_{10}	11	98.93	99.80
Z_{11}	12	99.41	99.90
Z_{12}	13	99.68	99.95
Z_{13}	14	99.83	99.98
Z_{14}	15	99.91	99.99
Z_{15}	16	99.95	99.994

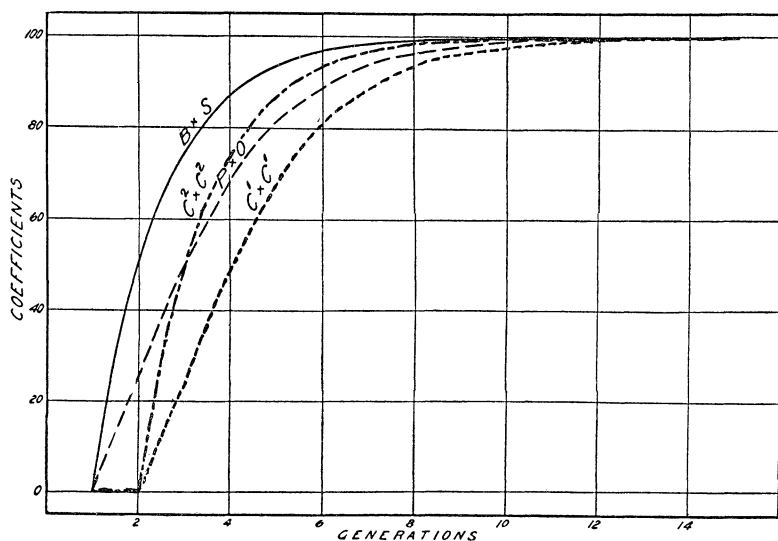


FIG. 1. Curves of inbreeding, showing (a) the limiting case of continued brother $\times$ sister breeding, wherein the successive coefficients of inbreeding have the maximum values; (b) continued parent $\times$ offspring mating; (c) continued first-cousin $\times$ first-cousin mating where the cousinship is double ($C^2 \times C^2$), and (d) continued first-cousin $\times$ first-cousin mating where the cousinship is single ($C^1 \times C^1$). The continued mating of uncle $\times$ niece gives the same curve as $C^1 \times C^1$.

The data of Table I are given graphically in Fig. 1, together with the curve for brother $\times$ sister and parent $\times$ offspring.

From the table and figure it is seen that with continued inbreeding according to any one of these four types the coefficient approaches the value 100. The rate of approach is different, however, in the different cases. The curves fall into two pairs. The brother $\times$ sister and the double cousin curves are precisely alike so far as concerns their curvature or shape at any given point. Similarly, the parent $\times$ offspring and single cousin curves are of the same shape. *The essential point of difference is that the cousin curves lag a generation behind the others.*

Let us now consider the question of the degree of inbreeding following continued matings of the avuncular type of relationship. Pedigree Table III gives a pedigree in which each mating is of uncle $\times$ niece.

PEDIGREE TABLE III (HYPOTHETICAL)
TO ILLUSTRATE THE MATING OF UNCLE $\times$ NIECE

X	{ a b }	{ c d e f }	{ g h i j k l }	{ m n o p q r s t }	{ u v w x y m n z 1 m n o p q h 2 3 m n o p q h r g h i j c d 4 5 }
Generation number	1	2	3	4	5

From this table it appears that the values of the coefficients of inbreeding will be exactly the same for this type of mating as in the case of single cousin mating. Or, in other words, Z 's form the following series.

TABLE II

VALUES OF COEFFICIENTS OF INBREEDING FOR CONTINUED
UNCLE $\times$ NIECE MATING

Coefficient	Number of Ancestral Generations	Value of Coefficient
Z_0	1	0
Z_1	2	0
Z_2	3	25.00
Z_3	4	50.00
Z_4	5	68.75
Z_5	6	81.25
etc.	etc.	etc. as in Table I

From the data presented in this and former papers it is clear that inbreeding continued for about ten generations, quite regardless of the *type* of mating, provided only it be *continuously* followed, leads to within one or two per cent. of complete "concentration of blood." The bearing of this result upon the general question of the degree of inbreeding which exists in the ancestry of our domestic animals to-day is obvious. To consider but a single case: In 1789³ a law was passed prohibiting the importation of cattle into the Island of Jersey. Hence it follows that all pure-bred Jersey cattle of the present time must be of the descendants of the relatively few animals on the Island in 1790. Taking three years as about the average generation interval in cattle, this means about forty generations since the Island was closed to importation. The concentration of lines of descent which must have occurred in this time merely by the dropping of lines and quite regardless of the type of mating is obvious. This is not the place to go in detail into the discussion of inbreeding in Jerseys, especially as I hope shortly to publish the results of an extensive study of this matter, but it seems desirable to emphasize the bearing of such hypothetical pedigrees for particular types of mating as are given in this and earlier papers, on the general problem of inbreeding.

It is possible to extend now somewhat the table of general equations given by Jennings⁴ for coefficients of inbreeding after

³ *Teste* Rees's Encyclopedia and H. S. Redfield, *Natl. Stockman and Farmer*, December 15, 1892.

⁴ AMER. NAT., Vol. XLIII, p. 695, 1914.

n generations of each particular type of mating. We have the following values, where n denotes the number of ancestral generations concerned, or, as Jennings puts it, the number of successive inbreedings which have taken place.

Type of Mating	Coefficient of Inbreeding
Self-fertilization	$\frac{2^n - 1}{2^n}$
Brother $\times$ sister	$\frac{2^n - 2}{2^n}$
Cousin $\times$ cousin, single	$\frac{2^n - 2n}{2^n}$
Cousin $\times$ cousin, double	$\frac{2^n - 2^2}{2^n}$ $\left\{ \begin{array}{l} \text{from } n = 2 \\ \text{to } n = \infty \end{array} \right.$
Parent $\times$ offspring	$\frac{2^n - n - 1}{2^n}$
Uncle $\times$ niece	$\frac{2^n - 2n}{2^n}$

RAYMOND PEARL

AN ATTEMPT TO PRODUCE MUTATIONS THROUGH HYBRIDIZATION

THERE is no more interesting problem to the experimental evolutionist than the one relating to the cause or causes of the origin of mutations. Until we are able to solve this problem we can only accept what the gods give in our breeding experiments. When a mutation arises it is usually a simple process to produce a pure stock. By mutation is meant any deviation from the normal type which reappears in some of the descendants. In the following experiment most of the abnormalities that were found never reappeared in the offspring.

My experiments have been confined to the fruit fly, *Drosophila ampelophila*, a species kept for years "under cultivation" at Columbia University. This species has proved to be very plastic, throwing off great numbers of mutant forms. At the suggestion of Dr. T. H. Morgan I crossed some of these mutants with wild stock of the same species from widely separated localities in order to test whether through hybridization mutations arise in greater numbers than in inbred stock.

The idea that new forms arise from crossing more or less closely related species is an old one. One finds many references in Darwin's works to this conception. For instance, in the "Origin of Species" Darwin says: